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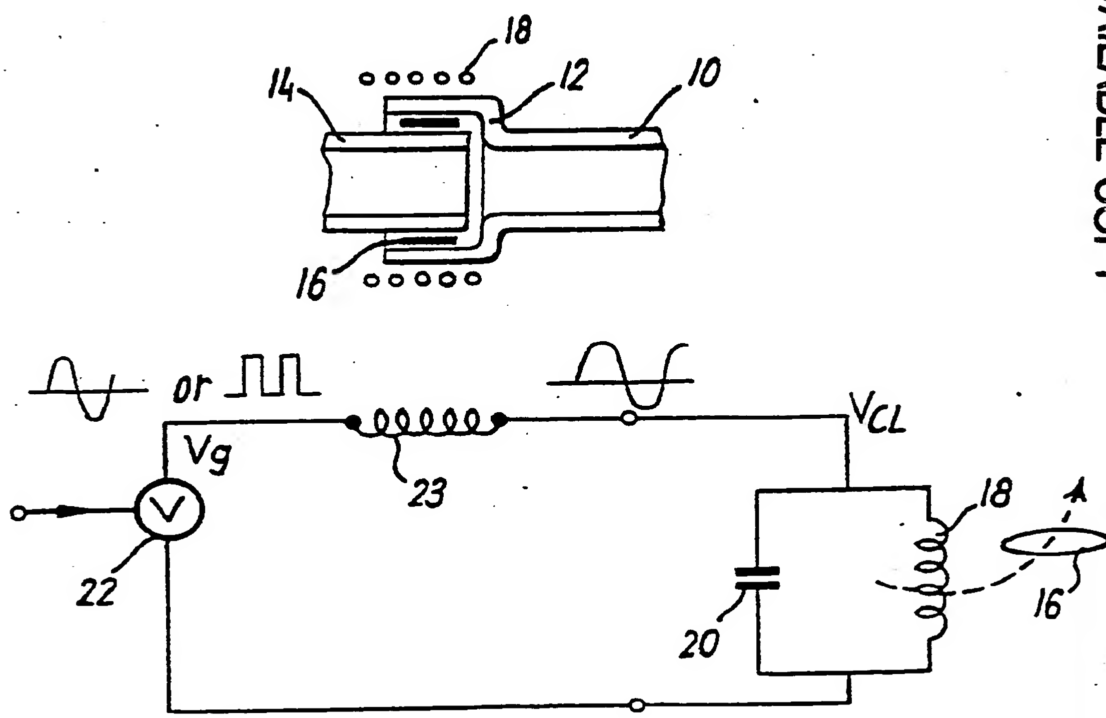
(54) Title: SENSING TEMPERATURE VARIATIONS IN A MATERIAL

(57) Abstract

In the welding together of plastics pipes (10, 14), a band (16) of electrically conductive material locates between the pipes at the joint and the latter is surrounded by a coil (18). A voltage is applied across a tuned circuit including the coil (18) and current is induced in the band (16) to heat the joint to the fusion temperature. The magnetic permeability of the band (16) alters and the effect on the tuned circuit results in changes in the phase angle of the coil voltage relative to the applied voltage. Comparison of the phase angles can give an indication of the temperature of the band (16) and further comparison with a reference can produce a signal for controlling the applied voltage and thus the temperature of the band (16).



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Sensing Temperature Variations in a Material

This invention relates to a method of and apparatus for sensing temperature variations in a material. The invention is particularly but not exclusively used in the joining of plastics pipes whilst inductively heating the joint with a conductive/magnetic material located at the region to be heated.

It is currently the practice in the welding together of plastics pipes to heat the joint parts separately and then fuse the parts together. Difficulties are however encountered in checking the correct location of the joint parts together.

According to one aspect of the present invention there is provided a method of sensing temperature variations in a material, said method comprising utilising means at a location remote from the material to both induce an electric current in the material and sense changes in a parameter of the material which occur in accordance with the changes in temperature in the material, and processing said changes in the parameter so as to determine the temperature of the material.

Preferably the inducing and sensing means to heat the material and comparing said changes in the parameter with a reference so as to produce a differential signal after comparison for controlling the current being induced and thus the temperature of the material.

Preferably also the changes in the parameter effect changes which can be sensed in voltage developed across the coil. Alternatively

the changes in the parameter effect changes which can be sensed in the phase of voltage developed across the coil relative to the phase of input voltage to the tuned circuit.

The parameter in which the changes are sensed may be the magnetic permeability or resistivity of the material.

According to another aspect of the present invention there is provided apparatus for sensing temperature variations in a material, said apparatus comprising means at a location remote from the material arranged to both induce an electric current in the material and sense changes in a parameter of the material which occur in accordance with changes in temperature in the material, and means for processing said changes in the parameter so as to determine the temperature of the material.

Preferably the sensing means comprises a coil in a tuned circuit, the quality factor and resonant frequency of which change in accordance with changes in the magnetic permeability and/or resistivity of the material.

An embodiment of the present invention will now be described by way of example only with reference to the accompanying drawings in which :-

Fig. 1 is a diagrammatic view of an arrangement for welding a pair of plastics pipes together, the control of which welding is effected by a method and apparatus according to the invention;

Fig. 2 is a circuit diagram of the apparatus for sensing temperature variations in a material used in the welding of Fig. 1 including a voltage phase comparison circuit;

Fig. 3 shows a comparison cimuit;

Fig. 4 shows a modified comparison circuit; and

Fig. 5 is a circuit diagram of a modified apparatus.

In various industrial processes it is desirable to sense the temperature of a material in a region where it is not possible to mount a temperature sensor with electrical connections connected thereto. For example, it may be desired to sense the temperature inside a sealed vessel to which access cannot be obtained with conventional sensors, or the temperature of an internal, inductively heated component in a surrounding material where a conventional sensor with connecting wires would degrade the integrity of the joint or assembly.

One particular example is the welding together of plastics pipes which may be butt welded or, as shown in Fig. 1 be connected by a spigot and socket arrangement.

Referring to the drawings, a pipe 10 formed of a termoplastic material has a socket portion 12 arranged to receive an end portion of a further pipe 14 which is to be welded into the socket portion 12 and which is also formed of a thermoplastic material. A band 16 of an electrically conductive material is located around the end of the pipe 14 between the latter and the spigot portion 12 of the pipe 10 and a coil for inducing an electric current in the band 16 as hereinafter described is located around the socket portion 12 co-axially with the band 16.

The coil 18 is located in parallel with a capacitor 20 in a tuned circuit, the latter being connected across a voltage generating apparatus 22. The latter is arranged to have a high output impedance by having an added output ballast impedance 23. When the circuit is energised the coil 18 creates a magnetic field having an operating frequency in the range from 50 Hz to high radio frequencies, the choice of frequency being influenced by the power level required, the generator circuit adopted, and the various statutory legislations and regulations relating to radion frequency interference and equipment safety regulations.

An induced current is therefore caused to flow in the band 16, the latter being of such material that the magnetic permeability thereof alters with variation in temperature within the temperature range to be measured. The band 16 is preferably a nickel steel alloy with a Curie point slightly higher than the temperature of fusion of the plastics pipes. The change in permeability results in the magnetic coupling co-efficient, the magnitude of the circulating current and hence the power drawn from the inducing coil, and the self inductance of the energising coil changing. These changes result in changes in the quality factor and the resonant frequency of the tuned circuit, with the quality factor $Q = \frac{WL}{R}$ where R is the combined effective resistance of the coil winding and reflected load due to power dissipation in the band 16, and L is the effective inductance when in operating position relative to the band 16. At resonance, the voltage V_{CL} across the coil is in quadrature with the voltage Vg developed by the generator 22, and changes in the quality factor and resonant frequency of the tuned circuit effect changes in phase angle of the coil voltage relative to the generator voltage.

Changes in phase angle are pre-calibrated against changes in temperature in the band 16, such that when the voltages Vg and V_{CL} are compared in a phase comparator circuit 24 there is an indication of the temperature of the band 16. An output from the circuit 24 can be compared with a reference in a comparative amplifier 26 to produce a signal for passing to an amplitude control input of the generator 22 and correspondingly controlling the induced current and the temperature of the band 16. It will be appreciated that in an application such as the welding together of two plastics pipes, the fusion temperature and the time during which heating takes place at the fusion temperature can be critical to production of an acceptable joint quality. The system has numerous advantages over the current welding practice.

This phase demodulation technique also allows the circuit to sense that the band 16 is in position and of the correct material since absence of the band 16 will alter the resonant frequency and quality factor of the tuned circuit.

The band 16 can be perforated, or several small bands inserted close together to give a labyrinth seal. The use of a material having a low Curie temperature and being non-corrosive is obviously beneficial and there are a range of such alloy materials commercially available. As an alternative, the band may be formed of a plastics material loaded with a material giving electrically conductive and magnetic properties. Further the band may be an integral part of a pipe.

In a modification as shown in Fig. 4 the change in permeability of the material results in a change in the voltage developed across the coil 18. The coil voltage V_{CL} can then be related to the generator voltage Vg in a divider circuit 28. Changes in voltage ratio are pre-calibrated against changes in temperature in the band 16 such that, in operation the changes give an indication of the temperature of the band 16. The output from the divider circuit 28 is compared with a reference in a comparative amplifier 30 and a differential signal provided which can be passed to the amplitude control input of the generator 22 for control of the input voltage, the induced current, and therefore the heating of the band 16.

In a further modification the coil 18 can be provided in series with capacitor 20 in a tuned circuit and driven by a voltage generator.

In a modified apparatus shown in Fig. 5, the drive voltage Vg is generated by a system including a self oscillating power amplifier 32 controlled by a comparator feedback loop which includes a phase shifting circuit 34, and which senses amplitude and/or phase relation-

ship ratios, and/or frequency of oscillation of Vg and V_a.

This configuration allows for a range of induction coils for different work piece assemblies to be utilised with one generator without the need for the circuit operating frequency adjustment as the system is self tuning.

The feedback signal to the phase shifting circuit can be direct from Vg as shown or from additional turns on the inducing coil 18.

The invention can also be utilised to sense the temperature of a material whose resistivity varies with variation of temperature within the temperature range to be measured. Further, as an alternative to the voltage generator with the output ballast impedance, a constant current/constant power generator may be utilised in order to provide the high output impedance.

The drive voltage can be square wave or sine wave, as the quality factor of the tuned circuit reduces the magnitude of the harmonics and any spurious high frequency components in the generator output. A degree of "self regulation" of the temperature of the band 16 is achieved since a reduction in coil voltage as the magnetic permeability reduces also reduces the ~~voltage~~ current induced in the band 16.

Claims

1. A method of sensing temperature variations in a material characterised in that means (18) at a location remote from the material (16) is utilised to both induce an electric current in the material (16) and sense changes in a parameter of the material (16) which occur in accordance with the changes in temperature in the material (16), said changes in the parameter, being processed so as to determine the temperature of the material (16).

2. A method according to claim 1, characterised in that the inducing and sensing means (18) is utilised to heat the material (16), and said changes in the parameter are compared with a reference so as to produce a differential signal after comparison for controlling the current being induced and thus the temperature of the material.

3. A method according to claim 1 or 2, characterised by applying a generating voltage across a coil (18) which includes the electric current in the material (16), and comparing changes in phase angle of the coil voltage, resulting form changes in the parameter, with the generating voltage.

4. A method according to claim 1 or 2, characterised by applying a generating voltage across a coil (18) which induces the electric current in the material (16), and comparing changes in the ratio of the coil voltage to the generating voltage resulting from changes in the parameter.

5. A method according to any of claims 1 to 4 characterised by sensing changes in the magnetic permeability of the material.

6. A method according to any of claims 1 to 4, characterised by sensing changes in the resistivity of the material.

7. A method of connecting plastic pipes together, characterised by locating an end portion of a first pipe (14) within an end portion (12) of a second pipe (10) and providing an annular part (16) formed of a material having electrically conductive and magnetic properties, and sensing temperature variations in the material of the annular part (16) in accordance with the method of the preceding claims.

8. A method according to claim 7 when dependent on claim 3 or 4 wherein the coil (18) is located around said end portion (12) of said second pipe (10) coaxially with the annular part (16).

9. Apparatus for sensing temperature variations in a material, characterised in that said apparatus comprises means (18) at a location remote from the material (16) arranged to both induce an electric current in the material (16), and sense changes in a parameter of the material (16) which occur in accordance with changes in temperature in the material (16), and means (24, 28) for processing said changes in the parameter so as to determine the temperature of the material (16).

10. Apparatus according to claim 9 characterised in that the means for inducing the electric current and sensing changes in the parameter comprises a coil (18) in a tuned circuit, the quality factor and resonant frequency of which change in accordance with changes in the magnetic permeability and/or resistivity of the material (16).

11. Apparatus according to claim 10 characterised in that the coil (18) is arranged in parallel with a capacitor (20) in the tuned circuit.

12. Apparatus according to claim 10, characterised in that the coil is arranged in series with a capacitor in the tuned circuit.

13. Apparatus according to any of claims 10 to 12, characterised by a voltage generator (22), means for applying the generated voltage across the coil (18), and means (26) for comparing changes in phase angle of the coil voltage resulting from changes in the magnetic permeability and/or resistivity of the material (16) relative to the generator voltage.

14. Apparatus according to any of claims 10 to 12, characterised by a voltage generator (22), means for applying the generated voltage across the coil (18), and means (30) for comparing changes in the ratio of the coil voltage, to the generating voltage resulting from changes in the magnetic permeability and/or resistivity of the material (16).

15. An arrangement for connecting plastics pipes together, characterised in that said arrangement comprises apparatus for sensing temperature variations in the material according to any of claims 10 to 14, wherein the coil (18) is adapted to locate co-axially around the intended joint between a pair of pipes (10, 14).

AMENDED CLAIMS
(received by the International Bureau on 28 June 1982 (28.06.82))

1 - 15 (cancelled)

16.(new) A method of sensing temperature variations in a material characterised in that means (18) at a location remote from the material (16) is utilised to both heat the material (16) by inducing an electric heating current in the material (16) and to sense changes in a parameter of the material (16) which occur in accordance with the changes in temperature in the material (16), said changes in the parameter are compared with a reference so as to produce a differential signal after comparison for controlling the current being induced and thus the temperature of the material.

17.(new) A method according to claim 16, characterised by applying a generating voltage across a coil (18) which induces the electric current in the material (16), and comparing changes in phase angle of the coil voltage, resulting from changes in the parameter, with the generating voltage.

18.(new) A method according to claim 16, characterised by applying a generating voltage across a coil (18) which induces the electric current in the material (16), and comparing changes in the ratio of the coil voltage to the generating voltage resulting from changes in the parameter.

19.(new) A method according to any of claims 16 to 18, characterised by sensing changes in the resistivity of the material.

20.(new) Apparatus for sensing temperature variations in a material, characterised in that said apparatus comprises means (18) at a location

remote from the material (16) arranged to both heat the material by inducing an electric heating current in the material (16), and to sense changes in a parameter of the material (16) which occur in accordance with changes in temperature in the material (16), and means (24, 28) for comparing said changes in the parameter with a reference so as to produce a differential signal for controlling the current being induced and thus the temperature of the material (16).

21.(new) Apparatus according to claim 20 characterised in that the means for inducing the electric current and sensing changes in the parameter comprises a coil (18) in a tuned circuit, the quality factor and resonant frequency of which change in accordance with changes in the magnetic permeability and/or resistivity of the material (16).

22.(new) Apparatus according to claim 21 characterised in that the coil (18) is arranged in parallel with a capacitor (20) in the tuned circuit.

23.(new) Apparatus according to claim 21, characterised in that the coil is arranged in series with a capacitor in the tuned circuit.

24.(new) Apparatus according to any of claims 21 to 23, characterised by a voltage generator (22), means for applying the generated voltage across the coil (18), and means (26) for comparing changes in phase angle of the coil voltage resulting from changes in the magnetic permeability and/or resistivity of the material (16) relative to the generator voltage.

25.(new) Apparatus according to any of claims 21 to 23, characterised by a voltage generator (22), means for applying the generated voltage

across the coil (18), and means (30) for comparing changes in the ratio of the coil voltage, to the generating voltage resulting from changes in the magnetic permeability and/or resistivity of the material (16).

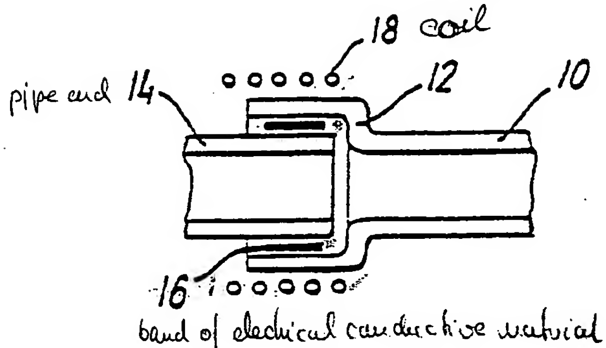

FIG. 1

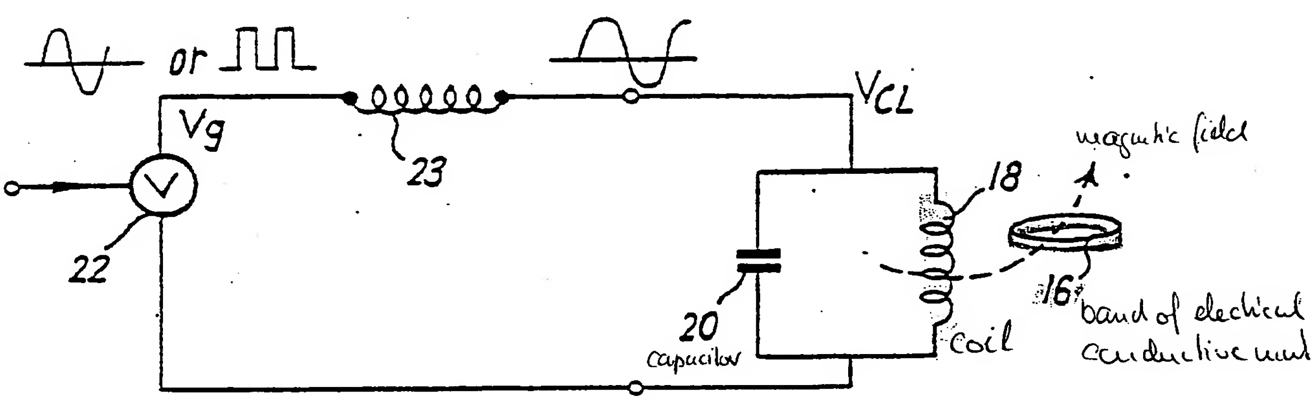

FIG. 2

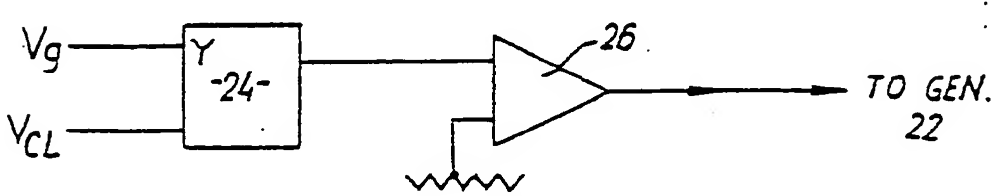

FIG. 3

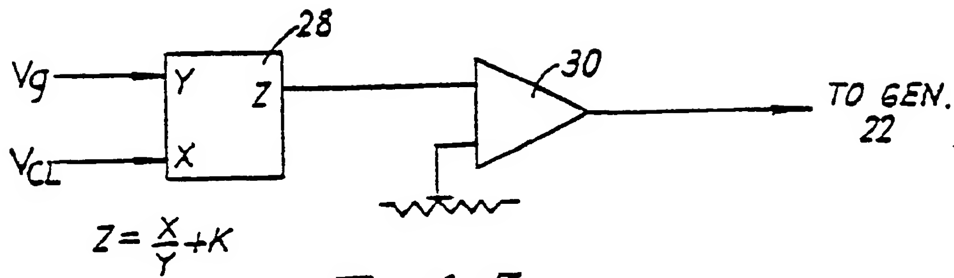

FIG. 4

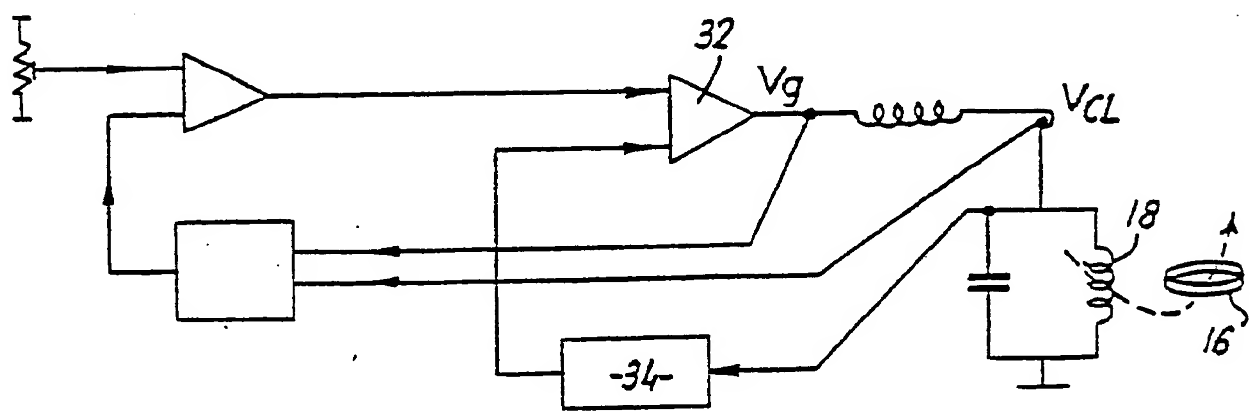

FIG. 5

INTERNATIONAL SEARCH REPORT

International Application No PCT/GB 82/00014

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [3]

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC^3: G 01 K 7/38; B 29 C 27/04

II. FIELDS SEARCHED

Minimum Documentation Searched [4]

Classification System	Classification Symbols
IPC^3	G 01 K; B 29 C

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [5]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [14]

Category *	Citation of Document, [16] with indication, where appropriate of the relevant passages [17]	Relevant to Claim No. [18]
X,Y	WO, A, 80/02124 (HAXEY ENGINEERING LTD.) 16 October 1980 see the introduction; figures 1-5; page 6, line 32 - page 10, line 25 & EP, A, 0026191 (published 8 April 1981) --	1,2,5,7-9, 10,15
X,Y	FR, A, 2163445 (NIPPON KOKAN K.K.) 27 July 1973 see the introduction; figures 1,2,3; page 2, line 33 - page 4, line 17; page 5, lines 3-9 & DE, A, 2256887 (published 28 June 1973) & GB, A, 1343270 (Published 10 January 1974) & JP, A, 48066877 (published 13 September 1973) --	1,3,5,9-11
A	EP, A, 0011862 (GENERAL ELECTRIC CY.) 11 June 1980 see page 5, line 16 - page 8, line 25; page 10, line 5 - page 11, line 4; figures 1,2,3,4 ------	1,5,9,10

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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search [2]	Date of Mailing of this International Search Report [2]
14th April 1982	28th April 1982
International Searching Authority [1]	**Signature of Authorized Officer** [20]
EUROPEAN PATENT OFFICE	G.L.M. Kruydenberg

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